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(71) Applicant: Mitsubishi-Kasei Technoengineers Ltd.
No. 2-12, Sendagaya 4-chome Shibuya-ku
Tokyo(JP)

(72) Inventor: Ando, Masao c/o Mitsubishi-Kasai Technoengineers Ltd. No. 2-12 Sendagaya 4-chome
Shibuya-ku Tokyo(JP)
Inventor: Tanimura, Masatake c/o Mitsubishi-Kasai
Technoengineers Ltd. No. 2-12 Sendagaya 4-chome
Shibuya-ku Tokyo(JP)
Inventor: Tamura, Masao c/o Mitsubishi-Kasai Technoengineers Ltd. No. 2-12 Sendagaya 4-chome
Shibuya-ku Tokyo(JP)

(74) Representative: Hansen, Bernd, Dr.rer.nat. et al
Hoffmann, Eitle & Partner Patentanwälte
Arabellastrasse 4
D-8000 München 81(DE)

(54) Method of chromatographic separation.

(57) A chromatographic separation process employing fewer beds packed with an adsorbent, while enabling separation of feedstock fluid, containing a plurality of components which have different degrees of affinity for the adsorbent, into constituent fractions which are withdrawn separately. According to at least one preferred embodiment, a step of supplying feedstock fluid to the simplified separation apparatus is preceded and followed by a step of circulating the fluid through the apparatus, a cycle of supply - desorbing -circulation being carried out repeatedly.

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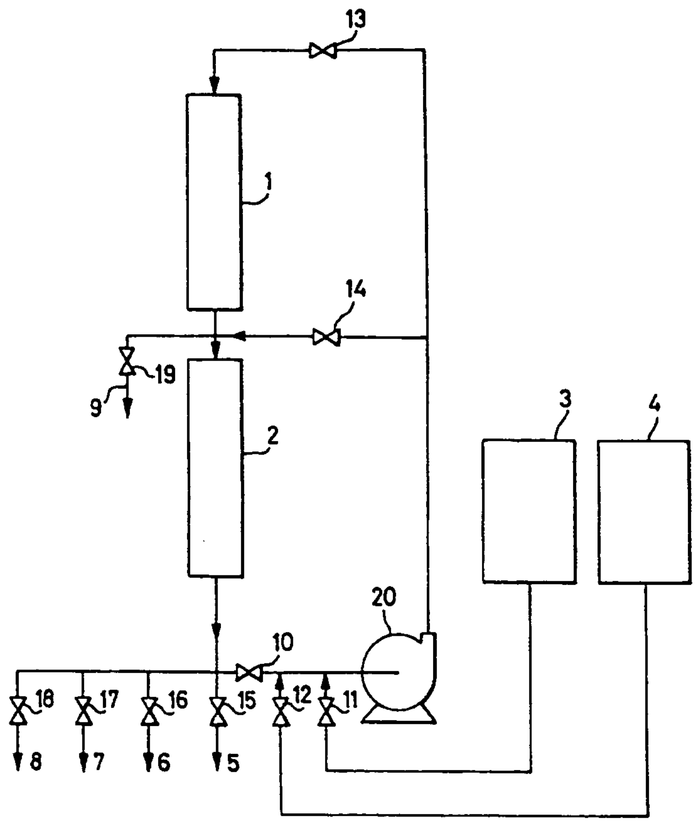
FIG. 1



METHOD OF CHROMATOGRAPHIC SEPARATION

Background of the Invention

The present invention relates to a method by which a fluid mixture containing a plurality of components is chromatographically separated into three or more fractions enriched in the respective components.

Chromatographic separation techniques employing solid adsorbents are extensively used in industrial applications. Among the processes currently in commercial use are a continuous chromatographic separation method that employs a simulated moving-bed system as described in Japanese Patent Publication No. 37008/1981. These methods of chromatographic separation have met with some commercial success, but they are basically designed for separating a mixture of components into two fractions. Great difficulty has been encountered in achieving separation into three or more fractions using these methods.

A simulated moving-bed system requires a minimum of four packed beds. The chromatographic separation method disclosed in Unexamined Published Japanese Patent Application No. 37008/1981 requires three or four packed beds, and the equipment it employs is complicated and expensive.

Further, a method of separation into components A and B has been known in USP 4,267,054 (Japanese Patent Publication No. Sho-60-55162). The USP discloses a method for the chromatographic separation of each of the soluble components of a feed solution containing as major components (1) a component A which is relatively less adsorbed by a solid adsorbent having ion-exchanging or molecular sieve action and (2) a component B which is more selectively adsorbed by the solid adsorbent having ion-exchanging or molecular sieve action, the solid adsorbent having its adsorbency restored by displacing selectively adsorbed components.

However, the above-mentioned method is achieved by only chromatographic separation of the components A and B.

Summary of the Invention

In view of the foregoing deficiencies, an object of the present invention is to provide a chromatographic process that employs simple equipment to achieve efficient separation of mixture of components into three or more fractions, which separation has been considered difficult to achieve by previously-employed methods.

The process of the present invention which is capable of attaining this object is basically of a type wherein a feedstock fluid, containing a plurality of components having different degrees of affinity for an adsorbent, is supplied into a chromatographic separation system in which the upstream end of a bed packed with the adsorbent is connected to its downstream end by a fluid channel so as to enable the circulation of fluids. The feedstocks fluid is passed through the packed bed from its upstream end to its downstream end to form adsorption zones having the concentration distribution of the respective components, followed by subsequent separation into three or more fractions. In this process, the feedstock fluid or a desorbent fluid is supplied into the packed bed at the upstream end so that zones enriched in the respective components are withdrawn as separate frictions, with at least part of the zones in which the respective components are present in admixture being retained within the bed as a non-withdrawal zone. This process is also characterized in that fluids in the packed bed are circulated without supplying any fluid into the bed or withdrawing any fluid therefrom, so that the non-withdrawal zone is situated adjacent to the zone in which the feedstock fluid is supplied, thereby replacing the latter zone with a zone to be withdrawn at the time when the feedstock fluid is supplied into the bed.

Brief Description of the Drawings

Fig. 1 is a schematic diagram of a chromatographic separation apparatus that may be employed to implement the process of the present invention;

Fig. 2 shows how the concentration distribution of each of the components in a feed mixture in a packed bed varies as it is passed through successive stages of chromatographic separation process;

Fig. 3 shows elution curves that compare the results of chromatographic separation by a single pass with those of chromatographic separation as effected by the process of the present invention; and

Fig. 4-7 show elution curves for individual components in a feed mixture that were respectively attained in Examples 1-3, a reference example, and Example 4.

Detailed Description of the Invention

The present invention provides a process of semicontinuous chromatographic separation that is performed by repeating the procedures of chromatographic separation batchwise using the chromatographic separation system described in the Summary of the Invention. This process includes the following steps:

(i) supplying a feedstock fluid into a packed bed at its upstream end while a fraction enriched in a certain component is withdrawn from the downstream end of the bed (this step is hereinafter referred to as a supply step);

(ii) supplying a desorbent fluid into the packed bed at its upstream end so as to withdraw a fraction enriched in another component from the downstream end of the bed (this step is hereinafter referred to as a desorption step); and

(iii) circulating the fluids in the packed bed without supplying any fluid to the bed or withdrawing any fluid from the bed, thereby allowing a zone containing a plurality of components to be moved to the upstream end of the packed bed (this step is hereinafter referred to as a circulation step).

These three steps are cyclically performed in an order that depends on the feedstock fluid to be processed by chromatographic separation.

In separation of three or more components into three fractions at least two zones occur in which a plurality of components are present in mixture. In such a case, it is preferred that components other than those which have the slightest and lowest degree of affinity for the adsorbent are recovered in the supply step, with a circulation step being provided both before and after the supply step so that the entire process is performed in the order of supply step - circulation step -desorption step - circulation step. Any other component is obtained as a fraction from the desorption step divided into two or more sub-steps.

The process of the present invention hereinafter will be described in greater detail with reference to the accompanying drawings.

Fig. 1 is a schematic diagram of a chromatographic separation apparatus that may be employed to implement the process of the present invention. Beds 1 and 2 are packed with an adsorbent. These beds may be the same or different in terms of bed capacity or the volume of the adsorbent used. Also shown in Fig. 1 is a tank 3 for the feedstock fluid; a tank 4 for the desorbent fluid, lines 5-9 for withdrawing associated fractions, valves 10-19 for controlling flow of fluids and associated fractions, and a circulating pump 20.

Fig. 2 shows the results of computer simulation of chromatographic separation that was performed on three components, A, B, and C, having different degrees of affinity for an adsorbent according to the process of the present invention. In this figure, the concentration distribution of each of the components, A, B, and C, in the packed bed that is attained at the time of completion of each step is indicated by a curve labelled with the same symbol A, B, or C. In the supply step, the feedstock is supplied into the packed bed at its upstream end (the left end of Fig. 2) while component B is withdrawn from its downstream end (right end of Fig. 2). In desorption step 1, the desorbent is supplied into the packed bed at its upstream end while the component C is withdrawn from the downstream end. In desorption step 2, the desorbent is supplied into the packed bed at its upstream end and component A is withdrawn from the downstream end.

As is clear from Fig. 2, a zone in which components A and B are present in admixture is allowed to move to the upstream end of the packed bed in the circulation step conducted before applying the feedstock fluid. In the circulation step following the supply of the feedstock fluid, a zone in which components B and C are present in admixture is allowed to move to the upstream end of the bed. In this way, the two mixed zones are situated adjacent to the upstream and downstream ends of the zone in which the feedstock fluid is supplied, with the result that the zone enriched in component B replaces the feedstock fluid supplied zone. Instead of withdrawing the zones in which a plurality of components are present in admixture, they are circulated in such a way that they are situated adjacent to the upstream and downstream ends of the zone in which the feedstock fluid is supplied.

As a result, elution curves that are indicated by solid lines in Fig. 3 are attained and the separation efficiency is sufficiently improved to ensure the recovery of highly pure and concentrated fractions. The curves indicated by dashed lines in Fig. 3 are elution curves showing the results of of separation by a single pass. The curves indicated by solid lines are elution curves showing the state of equilibrium that is attained after performing the process of the present invention through 11 cycles by circulating zone R_1 in which components A and B are present in mixture and zone R_2 in which components B and C are present

in mixture.

In order to ensure that the zone in which the feedstock fluid is supplied is properly replaced by a zone containing a desired product fraction (i.e., a fraction to be withdrawn from the downstream end of the packed bed in the supply step) in the process of the present invention, it is required that the fluids present in these two zones be equal in volume. In practical applications of chromatographic separation, however, this requirement cannot always be met because of the need to recover a product of interest at a desired purity or yield.

If the volume of the desired product fraction is larger than that of the feedstock fluid to be supplied, an additional supply step is provided in which a desorbent fluid is supplied to the packed bed either immediately before or after the feedstock is supplied, so that the product fraction is withdrawn from the downstream end of the packed bed in an amount corresponding to the difference in volume. In the case where this additional step is provided immediately before or after the circulation step, the desorbent fluid must be supplied in the additional step which is not at the upstream end of the packed bed, but rather is at the middle portion thereof, in which the concentration of each component is either zero or substantially zero. This is necessary to ensure that each of the zones containing a plurality of components in mixture that was or is allowed to move in the circulation step will be situated adjacent to the zone in which the feedstock fluid is supplied. In ordinary cases, the desorbent fluid is supplied to the second of two series-connected packed beds (i.e. the bed 2) as shown in Fig. 1.

If the volume of the product fraction to be recovered is smaller than that of the feedstock fluid to be supplied, an additional step is provided in such a way that the step of supplying the feedstock fluid while withdrawing the product fraction is immediately preceded or followed by the step of supplying the feedstock fluid while withdrawing a second fraction. In the case where this additional step is provided immediately after or before the circulation step, the second fraction must be withdrawn from the middle portion of the packed bed in order to ensure that at least part of the zones in which a plurality of components are present in admixture is retained in the bed as a non-withdrawal zone.

As described above, the zones containing a plurality of components in mixture is allowed to circulate so that the separation of the plurality of components is remarkably promoted. However, if no high separation efficiency is required, either one of the circulating steps may be omitted. In this case, the process may be performed in the order of supply step - circulation step - desorption step, or in the order of supply step - desorption step - circulating step.

As described on the foregoing pages, the process of the present invention includes many variations depending upon the feedback to be processed by chromatographic separation and on the separating conditions. Typical process variations that can be realized by employing the apparatus shown in Fig. 1 are summarized in Table 1. Each of the processes designated by numbers 1, 5, 6, 7 and 8 in Table 1 can be performed with a single unit of packed bed, and all of the processes can be practiced with three or more units of packed bed. When, symbols are written in two rows for each process in Table 1, the upper symbol designates the fluid to be supplied into the packed bed and the lower symbol designates the fraction to be withdrawn from the packed bed; F signifies the feedstock fluid; D, desorbent fluid; a, b, c and d signify the principal components in the respective fractions. The numerals in parentheses are keyed to the packed beds shown in Fig. 1 into which the feedstock or desorbent fluid is supplied or from which a certain fraction is withdrawn; and R means circulation. The omission of a certain step is indicated by an oblique line. The components a, b, c and d have varying degrees of affinity for the adsorbent, with the affinity trend being as follows: a > b > c > d.

Table 1

	Supply Step		Circulation step	Desorption step			Circulation step
1	F (1) b (2)		R	D (1) a (2)	D (1) c (2)		R
2	F (1) b (2)	D (2) b (2)	R	D (1) a (2)	D (1) c (2)		R
3	F (1) b (2)	F (1) c (1)	R	D (1) a (2)	D (1) c (2)		R
4	F (1) b (2)	D (2) b (2)	R	D (1) a (2)	D (1) d (2)	D (1) c (2)	R
5	F (1) b (2)		R	D (1) a (2)	D (1) c (2)		
6	F (1) b (2)		R	D (1) a (2)	D (1) c (2)	D (1) b (2)	
7	F (1) b (2)			D (1) a (2)	D (1) c (2)		R
8	F (1) b (2)			D (1) b (2)	D (1) a (2)	D (1) c (2)	R

According to the process of the present invention, a mixture containing a plurality of components having different levels of affinity for an adsorbent can be separated into three fractions enriched in the respective components. Of course, the method of the present invention can be applied to separation of the mixture into four or more components but the efficiency of separation of a fourth and subsequent components is practically the same as what can be achieved in performing chromatographic separation batchwise by a single pass.

The process of the present invention is particularly advantageous to separate and purify various mixtures of saccharides or sugar alcohols using an alkali metal or alkaline earth metal type strong acidic cation-exchange resin as an adsorbent. Specific applications of this process include: separation of fructose from high fructose corn syrup. Separation of sucrose from molasses; separation of a starch hydrolyzate into maltose, maltodextrin, etc.; separation of a mixture containing isomaltose and isomaltodextrin into the respective components; and separation of a mixture containing sugar alcohols (e.g., sorbitol and maltitol) into the respective components.

The following examples are provided to illustrate further the present invention. However, various modifications of these examples can be carried out without departing from the scope of the present invention.

EXAMPLE 1

Using an apparatus of the type shown in Fig. 1, chromatographic separation of a feedstock (aqueous solution of a mixture of oligosaccharides) was conducted with a Na-form strong acidic cation-exchange resin (Diaion(tm) UBK-530 K) as an adsorbent and water as a desorbent, respectively. The adsorbent was packed into two series-connected columns each having an inside diameter of 35.5 mm and a packing height of 920

mm. A total of 1,810 ml of the adsorbent was packed to form packed beds.

While the packed bed was held at 75°C, the feedstock fluid (cane molasses) was passed through the bed at a flow rate of 1000 ml/h for effecting cyclic operations of chromatographic separation accroding to the time schedule shown in Table 2 below.

Table 2

	Supplied Fluid	Withdrawn Fluid	Valve Opened	Time (min)
1	feedstock	Sucrose fraction	11, 13, 16	6.0
2	-	-	10. 13	18.0
3	water	reducing sugar fraction	12, 13, 15	8.4
4	water	nonsugar fraction	12, 13, 17	20.4
5	-	-		4.8

Upon completion of 11 cycles, a steady state was reached and the elution curves shown in Fig. 4 were obtained. The y-axis of the graph in Fig. 4 represents the concentration of an individual component (g/ml) and the x-axis denotes time (min.); R_1 and R_2 represent zones to be circulated; and curves 21, 22 and 23 are elution curves for components reducing sugar, sucrose and non-sugar tively. The compositions of the respective fractions and the present recoveries of the respective components are shown in Table 3.

Table 3

	Feedstock	Sucrose Fraction	Reducing Sugar Fraction	Non-Sugar Fraction
Reducing Sugar	12.0 %	0.1 %	98.1 %	4.5 %
Sucrose	55.7 %	87.4 %	0.2 %	23.9 %
Non-Sugar	32.3 %	12.5 %	1.7 %	71.7 %
Concen-tration	47.0 %	27.0 %	4.4. %	5.9 %
Recovery		84.2 %		

EXAMPLE 2

A feedstock having the composition shown in Table 6 was subjected to chromatographic separation according to the time schedule shown in Table 5, using the same apparatus as what was employed in Example 1 except that Diaion(tm) UBK-530 (Na-form strong acidic cation-exchange resin) was used as an adsorbent, and flow rate was 460 ml/h. Elution curves for the respective components that were obtained in a steady state are shown in Fig. 5, in which R_1 and R_2 represent zones to be circulated, and curves 31, 32 and 33 refer to the respective components, viz., G_1, G_2 and G_3+ content. The compositions of the respective fractions obtained and the percent recoveries of the respective components are shown in Table 6.

Table 5

Step	Supplied Fluid	Withdrawn Fluid	Valves Opened	Time (min)
1	feedstock	fraction G_2	11, 13, 16	15.7
2	water	fraction G_2	12, 14, 16	5.2
3	-	-	10, 13	26.1
4	water	fraction G_1	12, 13, 15	32.6
5	water	fraction G_3+	12, 13, 17	32.6
6	-	-	10, 13	6.5

Table 6

	Feedstock	Fraction G_1	Fraction G_2	Fraction G_3+
G_1	41.2%	3.5%	95.0%	2.8%
G_2	27.0%	70.9%	4.6%	4.1%
G_3+	31.8%	25.6%	0.4%	93.1%
Concentration	60%	18.0%	14.4%	8.7%
Recovery		89.0%	96.7%	71.9%

EXAMPLE 3

A feedstock beet molasses having the composition shown in Table 8 was subjected to chromatographic separation according to the time schedule shown in Table 7, using the same apparatus and adsorbent as what was employed in Example 1, except flow rate was 1200 ml/h. Elution curves obtained for the respective components after a steady state was reached are shown in Fig. 6, in which R represents a zone to be circulated, and curves 41, 42, 43 and 44 refer to the respective components, i.e., reducing sugar, sucrose, rafinose and non-sugar. The compositions of the respective fractions obtained and the percent recoveries of the respective components are shown in Table 8.

Table 7

	Supplied Fluid	Withdrawn Fluid	Valves Opened	Time (min)
1	feedstock	Sucrose fraction 1	11, 13, 16	8.0
2	-	-	10, 13	12.5
3	water	Reducing Sugar Fraction	12, 13, 15	8.0
4	water	Non-Sugar Fraction	12, 13, 17	8.0
5	water	Sucrose Fraction 2	12, 13, 16	12.5

Table 8

	Feedstock	Sucrose Fraction	Reducing Sugar Fraction	Non-Sugar Fraction
Reducing Sugar	7.3 %	1.0 %	98.3 %	15.4 %
Sucrose	88.6 %	96.0 %	1.7 %	30.8 %
Raffinose	3.3 %	2.9 %	-	26.9 %
Non-Sugar	0.8 %	0.1 %	-	26.9 %
Concentration	60.0 %	24.4 %	4.6 %	1.8 %
Recovery		99.0 %	80.0 %	

EXAMPLE 4

A feedstock having the composition shown in Table 12 was subjected to chromatographic separation according to the time schedule shown in Table 11, using the same apparatus as what was employed in Example 1, except that a Ca-form strong acidic cation-exchange resin (Diaion (tm) UBK-535) was used as an adsorbent, and flow rate was 460 ml/h. Elution curves obtained for the respective components after a steady state was reached are shown in Fig. 7, in which R_1 and R_2 represent zones to be circulated, and curves 51, 52, 53 and 54 refer to the respective components, i.e., sorbitol, maltitol, DP_3 and DP_4+. The compositions of the respective fractions obtained and the percent recoveries of the respective components are shown in Table 12.

Table 11

Step	Supplied Fluid	Withdrawn Fluid	Valves Opened	Time (min)
1	feedstock	maltitol fraction	11, 13, 16	26.1
2	water	maltitol fraction	12, 14, 16	15.7
3	-	-	10, 13	33.9
4	water	sorbitol fraction	12, 13, 15	19.6
5	water	DP_4+ fraction	12, 13, 18	41.7
6	water	DP_3 fraction	13, 13, 17	24.8
7	-	-	10, 13	6.5

Table 12

	Feedstock	Sorbitol	Maltitol	DP_3 Fraction	DP_4+ Fraction
Sorbitol	4.5%	86.8%	0.6%	1.4%	7.5%
Maltitol	47.4%	10.1%	86.7%	10.7%	0.1%
DP_3	20.7%	0.2%	12.4%	70.5%	6.0%
DP_4+	27.4%	2.9%	0.3%	17.4%	86.4%
Concentration	60.8%	2.1%	23.4%	13.9%	13.0%
Recovery		40.0%	95.5%	60.5%	88.0%

Claims

1. In a chromatographic process of a type wherein a feedstock fluid, containing a plurality of components having different degrees of affinity for an adsorbent, is supplied into a chromatographic separation system in which the upstream end of a bed packed with the adsorbent is connected to its downstream end by a fluid channel to enable the circulation of fluids, and the feedstock fluid is passed through the packed bed for its upstream end to its downstream end to form adsorption zones having the concentration distributions of the respective components, followed by subsequent separation into three or more fractions, the improvement wherein one of the feedstock fluid and a desorbent fluid is supplied into the packed bed at the upstream end so that zones enriched in the respective components are withdrawn as separate fractions, with at least part of the zones in which the respective components are present in admixture being retained within the bed as a non-withdrawal zone, the improvement further comprising the step of circulating the fluids in the packed bed without supplying any fluid into the bed or withdrawing any fluid therefrom, so that said non-withdrawal zone is situated adjacent to the zone in which the fluid feedstock is supplied, thereby replacing the latter zone with a zone to be withdrawn at the time when said feedstock fluid is supplied to the bed.

2. A chromatographic process of a type wherein a feedstock fluid, containing a plurality of components having different degrees of affinity for an adsorbent, is supplied into a chromatographic separation system in which the upstream end of a bed packed with the adsorbent is connected to its downstream end by a fluid channel to enable the circulation of fluids, and the feedstock fluid is passed through the packed bed from its upstream end to its downstream end to form adsorption zones having the concentration distributions of the respective components followed by subsequent separation into three or more fraction said process including the following steps in sequence:

(i) supplying the feedstock fluid into the packed bed at its upstream end while a fraction enriched in a first component of the feedstock fluid is withdrawn from the downstream end of said bed;

(ii) supplying the desorbent fluid into the packed bed at its upstream end to withdraw a fraction enriched in a second component of the feedstock fluid from the downstream end of the bed; and

(iii) circulating the fluids in the packed bed without supplying any fluid into or withdrawing any fluid from the packed bed, thereby allowing a zone containing the component withdrawn in said step (i) and another component in admixture to be moved to the upstream end of the packed bed, said steps (i) to (iii) being performed cyclically.

3. A chromatographic process according to Claim 2 wherein a mixture is separated into three fractions by cyclically repeating the following steps:

(i) supplying the feedstock fluid into the packed bed at its upstream end while a fraction enriched in a component having a first affinity for the adsorbent is withdrawn from the downstream end of said bed;

(ii) circulating the fluids in the packed bed without supplying any fluid into the bed or withdrawing any fluid from the bed, thereby allowing a zone containing the component having said first affinity in admixture with a component having a second, higher affinity for the adsorbent to be moved to the upstream end of the packed bed;

(iii) supplying a desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in the component having said second affinity;

(iv) supplying the desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in a component having a third affinity, lower than said first affinity, for the adsorbent; and

(v) circulating the fluids in the packed bed without supplying any fluid into the bed or withdrawing any fluid from the bed, thereby allowing a zone containing the component having said first affinity in admixture with the component having said third affinity to be moved to the upstream end of the bed.

4. A chromatographic process according to Claim 2 wherein a mixture is separated into three fractions by cyclically repeating the following steps:

(i) supplying the feedstock fluid into the packed bed at its upstream end while a fraction enriched in a component having a first affinity for the adsorbent is withdrawn from the downstream end of said bed;

(ii) supplying a desorbent fluid into the packed bed at its middle portion to withdraw from the downstream end of said bed an additional fraction enriched in the component having said first affinity;

(iii) circulating the fluids in the packed bed without supplying any fluid into the bed or with drawing any fluid from the bed, thereby allowing a zone containing the component having said first affinity in admixture with a component having a second, higher affinity for the adsorbent to be moved to the upstream end of the packed bed;

(iv) supplying the desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in the component having said second affinity;

(v) supplying the desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in a component a third affinity, lower than said first affinity, for the adsorbent; and

(vi) circulating the fluids in the packed bed without supplying any fluid into the bed or withdrawing any fluid from the bed thereby allowing a zone containing the component having said first affinity in admixture with the component having said third affinity to be moved to the upstream end of the bed.

5. A chromatographic process according to Claim 2 wherein a mixture is separated into three reactions by cyclically repeating the following steps:

(i) supplying the feedstock fluid into the packed bed at its upstream end while a fraction enriched in a component having a first affinity for the adsorbent is withdrawn from the downstream end of said bed;

(ii) supplying an additional amount of the feedstock fluid into the packed bed at its upstream end while a fraction enriched in a component having a second, lower affinity for the adsorbent is withdrawn from the middle portion of the bed;

(iii) circulating the fluids in the packed bed without supplying any fluid into the bed or withdrawing any fluid from the bed, thereby allowing a zone containing the component having said first affinity in admixture with a component having a third affinity, higher than said first affinity, for the adsorbent to be moved to the upstream end of the bed;

(iv) supplying a desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in the component having said third affinity;

(v) supplying the desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in the component having said second affinity; and

(vi) circulating the fluids in the packed bed without supplying any fluid into the bed or withdrawing any fluid from the bed, thereby allowing a zone containing the component having said first affinity in admixture with the component having said second affinity to be moved to the upstream end of the packed bed.

6. A chromatographic process according to Claim 2 wherein a mixture is separated into four fractions by cyclically repeating the following steps:

(i) supplying the feedstock fluid into the packed bed at its upstream end while a fraction enriched in a component having a first affinity for the adsorbent is withdrawn from the downstream end of said bed;

(ii) supplying a desorbent fluid into the packed bed at its middle portion to withdraw from the downstream end of said bed an additional fraction enriched in the component having said first affinity for the adsorbent;

(iii) circulating the fluids in the packed bed without supplying any fluid into the bed or withdrawing any fluid from the bed, thereby allowing a zone containing the component having said first affinity for the adsorbent in admixture with a component having a second, higher affinity for the adsorbent to be moved to the upstream end of the packed bed;

(iv) supplying the desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in the component having said second affinity for the adsorbent;

(v) supplying the desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in a component having a third affinity, lower than said first affinity, for the adsorbent;

(vi) supplying the desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in a component having a fourth affinity, between said first and third affinities, for the adsorbent; and

(vii) circulating the fluids in the packed bed without supplying any fluid into the bed or withdrawing any fluid from the bed, thereby allowing a zone containing the component having said first affinity for the adsorbent in admixture with the component having said fourth affinity for the adsorbent to be moved to the upstream end of the packed bed.

7. A chromatographic process according to Claim 2 wherein a mixture is separated into three fractions by cyclically repeating the following steps:

(i) supplying the feedstock fluid into the packed bed at its upstream end while a fraction enriched in a component having a first affinity for the adsorbent is withdrawn from the downstream end of said bed;

(ii) circulating the fluids in the packed bed without supplying any fluid into the bed or withdrawing any fluid from the bed, thereby allowing a zone containing the component having said first affinity in admixture with a component having a second, higher affinity for the adsorbent to be moved to the upstream end of the packed bed;

(iii) supplying a desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in the component having said second affinity;

(iv) supplying the desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in a component having a third affinity, lower than said first affinity, for the adsorbent.

8. A chromatographic process according to Claim 2 wherein a mixture is separated into three fractions by cyclically repeating the following steps:

(i) supplying the feedstock fluid into the packed bed at its upstream end while a fraction enriched in a component having a first affinity for the adsorbent is withdrawn from the downstream end of said bed;

(ii) circulating the fluids in the packed bed without supplying any fluid into the bed or withdrawing any fluid from the bed, thereby allowing a zone containing the component having said first affinity in admixture with a component having a second, higher affinity for the adsorbent to be moved to the upstream end of the packed bed;

(iii) supplying a desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in the component having said second affinity;

(iv) supplying the desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in a component having a third affinity, lower than said first affinity, for the adsorbent; and

(v) supplying the desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in a component having said first affinity.

9. A chromatographic process according to Claim 2 wherein a mixture is separated into three fractions by cyclically repeating the following steps:

(i) supplying the feedstock fluid into the packed bed at its upstream end while a fraction enriched in a component having a first affinity for the adsorbent is withdrawn from the downstream end of said bed;

(ii) supplying a desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in the component having a second affinity, higher than said first affinity for the adsorbent;

(iii) supplying the desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in a component having a third affinity, lower than said first affinity, for the adsorbent; and

(iv) circulating the fluids in the packed bed without supplying any fluid into the bed or withdrawing any fluid from the bed, thereby allowing a zone containing the component having said first affinity in admixture with the component having said third affinity to be moved to the upstream end of the bed.

10. A chromatographic process according to Claim 2 wherein a mixture is separated into three fractions by cyclically repeating the following steps:

(i) supplying the feedstock fluid into the packed bed at its upstream end while a fraction enriched in a component having a first affinity for the adsorbent is withdrawn from the downstream end of said bed;

(ii) supplying a desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of said bed an additional fraction enriched in the component having said first affinity;

(iii) supplying the desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in the component having a second affinity, higher than said first affinity for the adsorbent;

(iv) supplying the desorbent fluid into the packed bed at its upstream end to withdraw from the downstream end of the bed a fraction enriched in a component a third affinity, lower than said first affinity, for the adsorbent; and

(v) circulating the fluids in the packed bed without supplying any fluid into the bed or withdrawing any fluid from the bed, thereby allowing a zone containing the component having said first affinity in admixture with the component having said third affinity to be moved to the upstream end of the bed.

FIG. 1

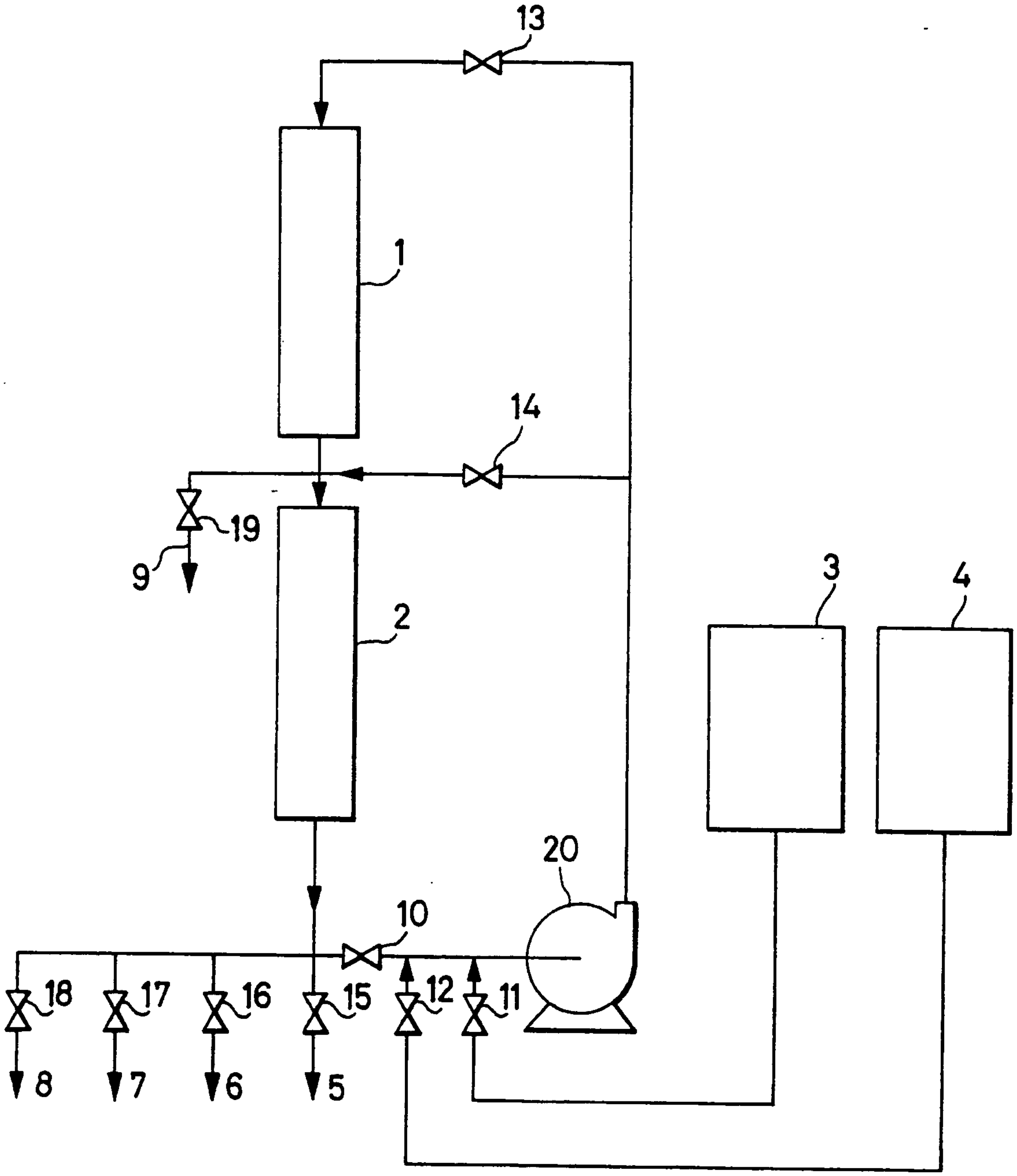


FIG. 2

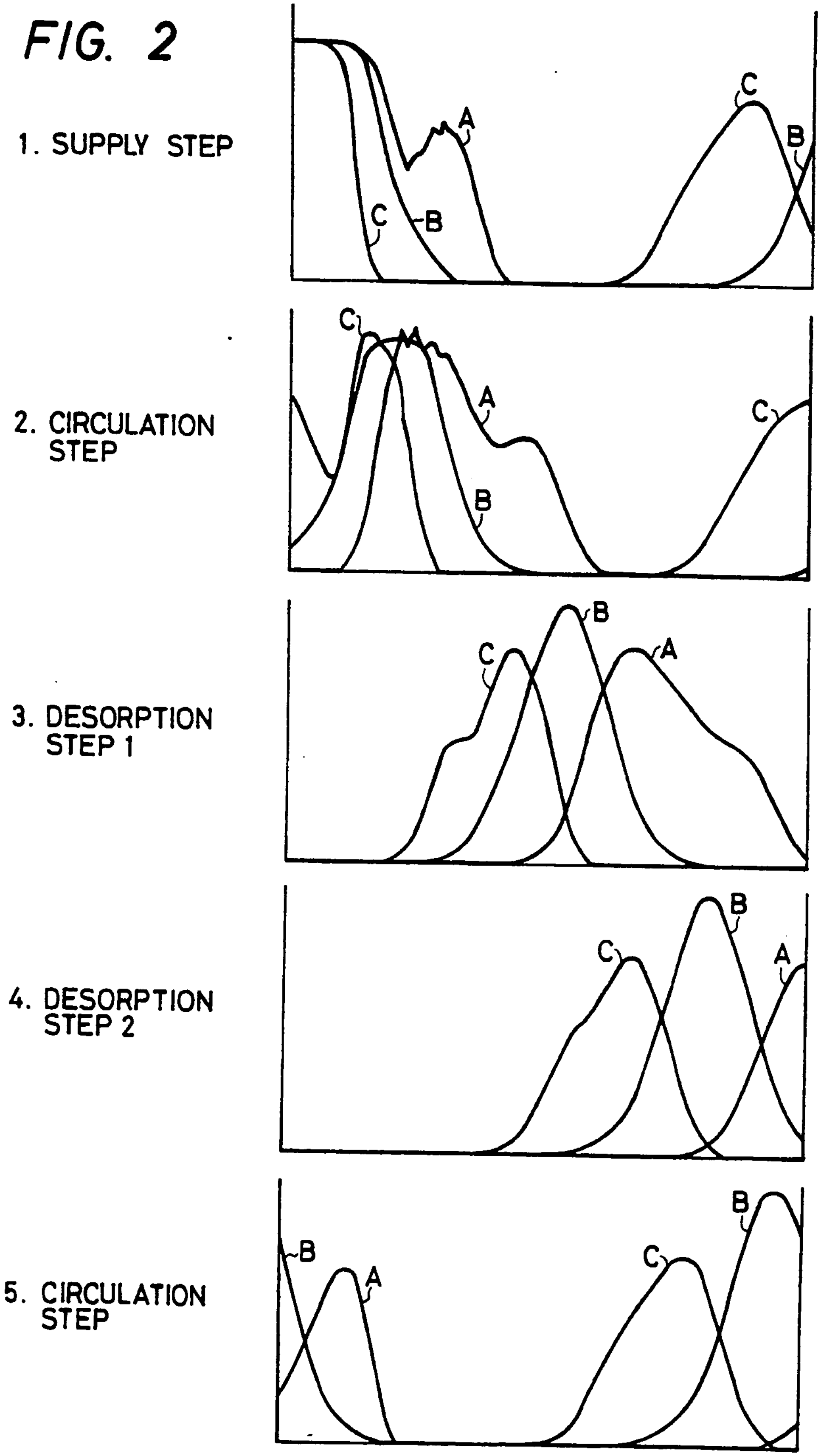

1. SUPPLY STEP
A
C
B
C
B
2. CIRCULATION STEP
C
A
B
C
3. DESORPTION STEP 1
B
C
A
4. DESORPTION STEP 2
B
C
A
5. CIRCULATION STEP
B
A
C
B

FIG. 3

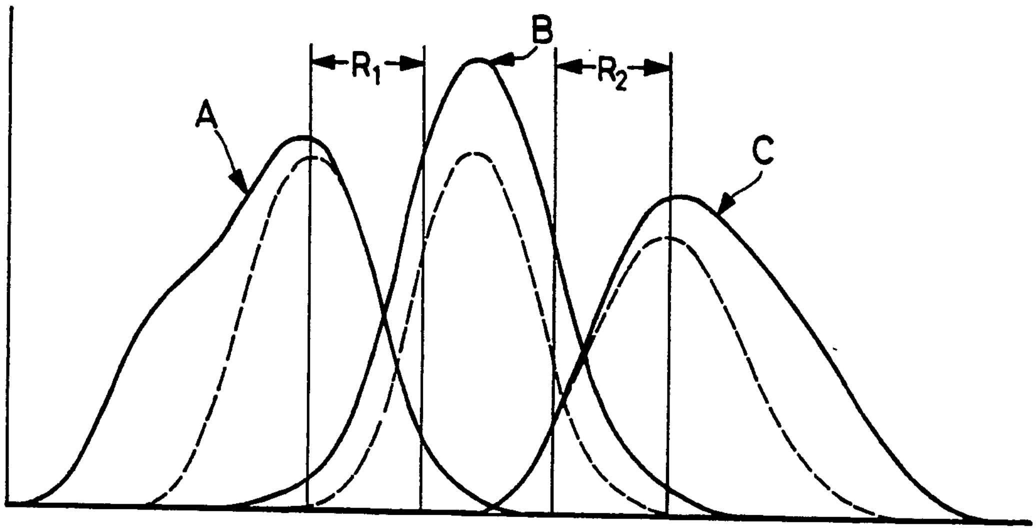

A
B
C
R1
R2

FIG. 4

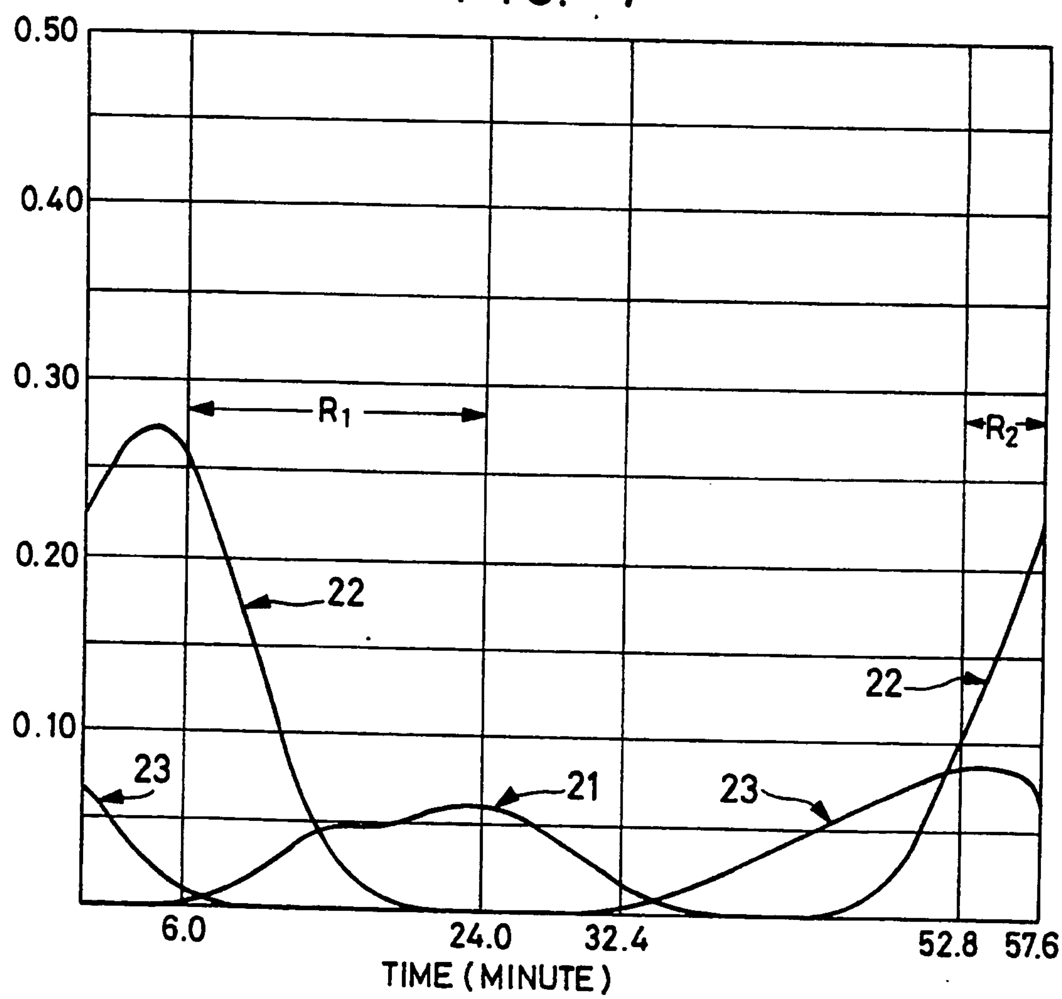

0.50
0.40
0.30
0.20
0.10
R1
R2
22
22
23
23
21
6.0
24.0
32.4
52.8
57.6
TIME (MINUTE)

FIG. 5

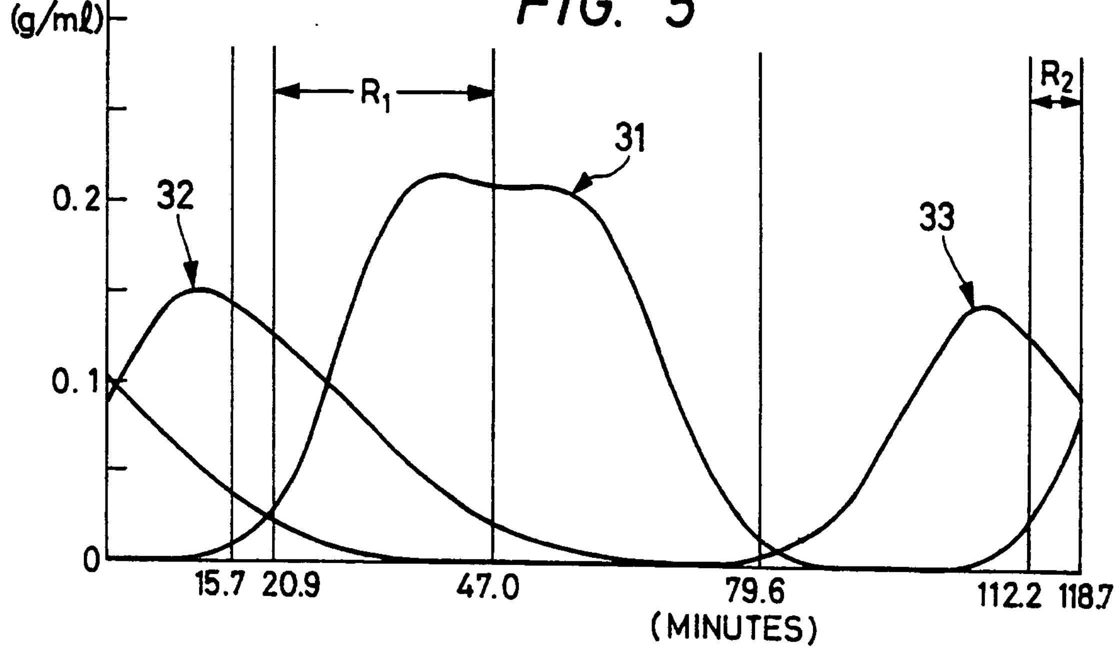

(g/mℓ)
0.2
0.1
0
R1
R2
31
32
33
15.7
20.9
47.0
79.6
112.2
118.7
(MINUTES)

FIG. 6

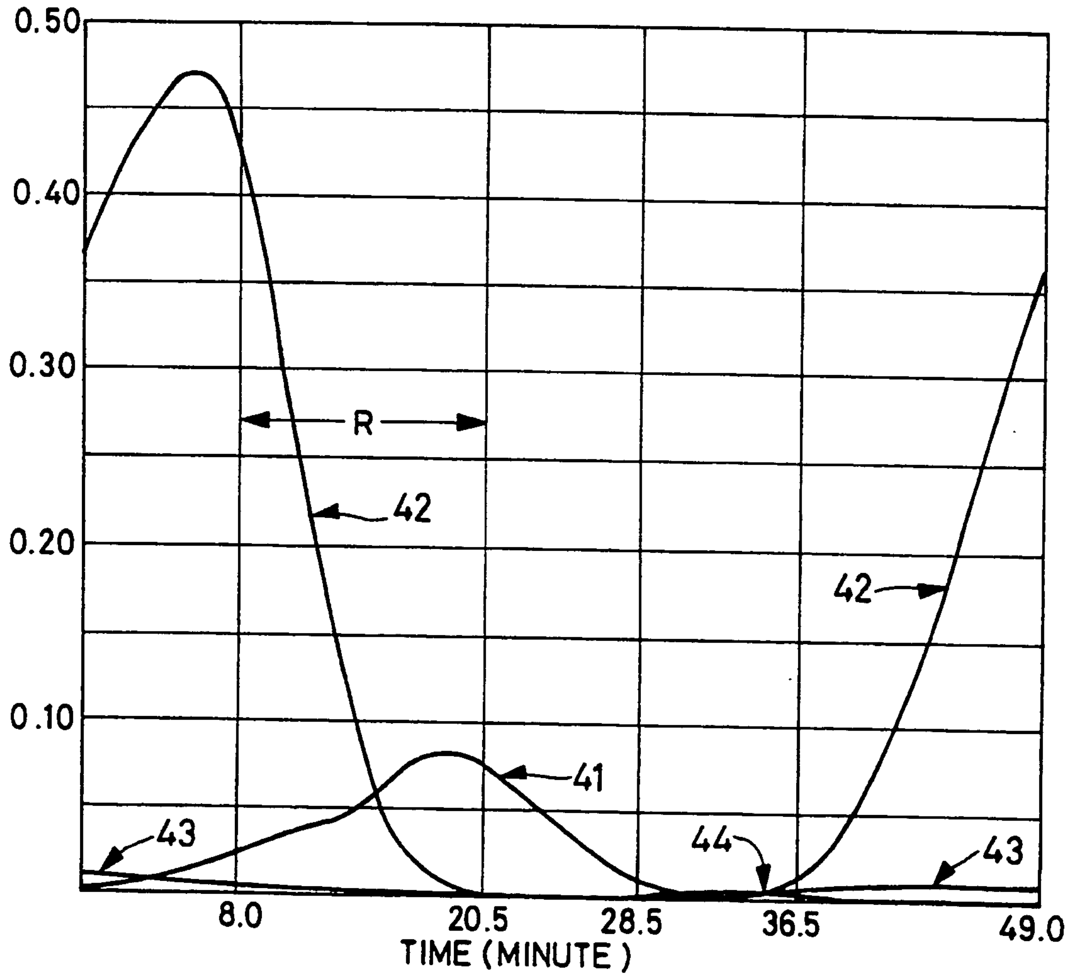
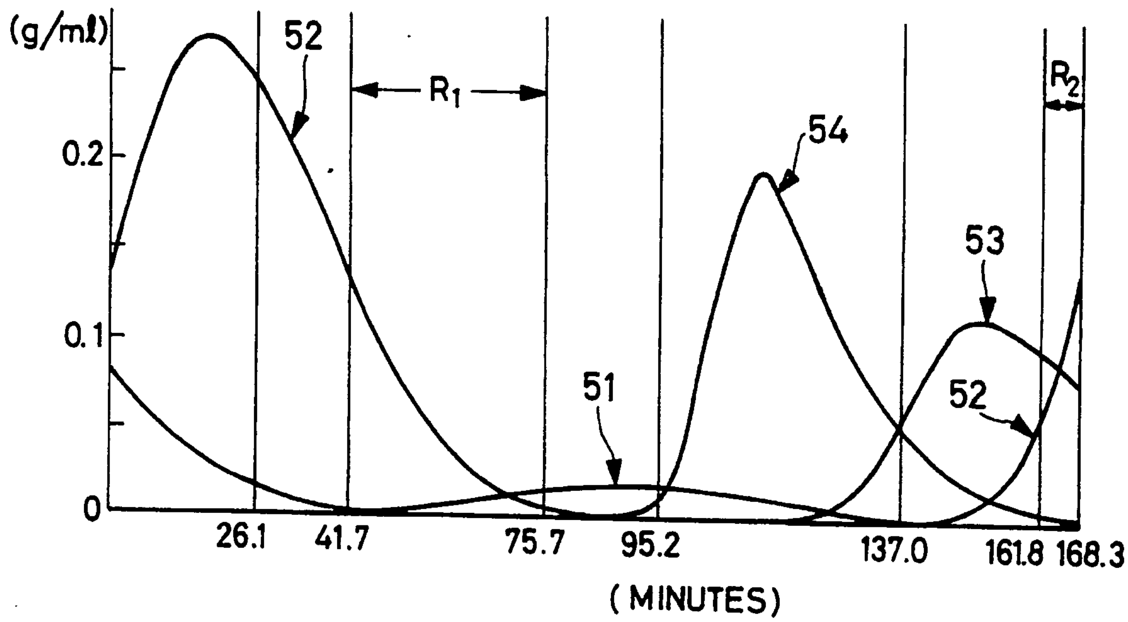

0.50
0.40
0.30
0.20
0.10
R
41
42
42
43
43
44
8.0
20.5
28.5
36.5
49.0
TIME (MINUTE)

FIG. 7


(g/ml)
0.2
0.1
0
52
R1
R2
54
53
51
52
26.1
41.7
75.7
95.2
137.0
161.8
168.3
(MINUTES)